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EDGEOOD ARSENAL  
TECHNICAL REPORT

EATR 4708

IMPACTION EFFICIENCY OF CYLINDRICAL COLLECTORS  
IN LAMINAR AND TURBULENT FLUID FLOW

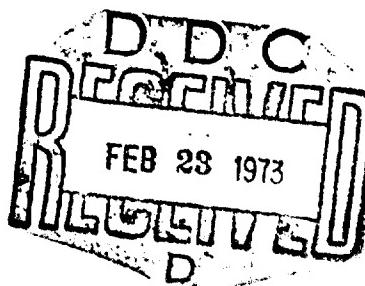
PART II. THE INTERCEPTION EFFECT.

by

Arthur K. Stuempfle

Chemical Laboratory

March 1973



DEPARTMENT OF THE ARMY  
Headquarters, Edgewood Arsenal  
Aberdeen Proving Ground, Maryland 21010

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EDGEWOOD ARSENAL TECHNICAL REPORT

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Task 1W062116A08402

DEPARTMENT OF THE ARMY  
Headquarters, Edgewood Arsenal  
Aberdeen Proving Ground, Maryland 21010

## FOREWORD

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## Acknowledgment

The author wishes to acknowledge the assistance of SP4 William Saunders in preparing the digital computer program.

## DIGEST

The inertial impaction of finite sized particles impinging on man-sized cylindrical elements in an ideal flow field has been studied by use of digital computer techniques. The interception effect resulting from consideration of finite particle size can theoretically increase the inertial impaction efficiency by an order of magnitude for small values of the particle inertial parameter and velocity scaling parameter. The theoretical results have been reduced to graphic form of impaction efficiency versus inertial parameter for all circumstances of interest in chemical operations and have been compared with the theoretical impaction efficiency data for point mass particles. The existence of a critical inertial parameter value for zero deposition is indicated but numerically is substantially less than the classical theory value without interception considerations.

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# IMPACTION EFFICIENCY OF CYLINDRICAL COLLECTORS IN LAMINAR AND TURBULENT FLUID FLOW. PART II. THE INTERCEPTION EFFECT

## I. INTRODUCTION.

The theory of inertial impaction of particles on cylindrical collectors in an ideal flow field has been developed in detail in a previous report.<sup>1</sup> The impaction efficiency for point mass particles has been shown to be a function of the inertial parameter, K, and the velocity scaling parameter,  $\phi$ . The particle size has been considered only in accounting for the drag force exerted on the particle as its mathematical trajectory around the cylinder was solved by use of digital computer techniques. Impaction efficiency has been defined as the ratio of the cross-sectional area of the original aerosol stream from which the trajectory of the particles intersects the collector surface to the projected area of the cylindrical collector in the direction of flow. However, because an impacting particle has a finite size as well as mass, the particle will intercept the cylinder when it is within a distance of one particle radius from the collector surface. Accounting for the finite size of the particle in the inertial impaction theory thereby results in impaction efficiencies that are greater than calculated efficiencies which exclude the interception effect.

Limiting estimates of the impaction efficiency for infinitely heavy particles and for massless particles that possess a finite size have been given by Ranz and Wong.<sup>2</sup> Davies and Peetz<sup>3</sup> computed numerous particle trajectories for three fluid flow regimes and examined the interception phenomena for particle to cylinder diameter ratios greater than 0.1. More recently, Householder and Goldschmidt<sup>4</sup> studied interception effects for particles with radii equal to and much greater than the collector radii. In addition, the latter authors provide a composite of experimental data for conditions likely to be encountered in chemical operations, that is, particle to collector ratios much less than 0.05. The objective of this report has been to incorporate the interception effect into the inertial impaction theory and to compute the impaction efficiencies of cylinders in potential fluid flow for all circumstances of interest to chemical operations.

## II. BACKGROUND THEORY.

Inertial impaction theory is based on a numerical solution of the equations of motion of a particle undergoing transport around a bluff body positioned in a fluid flow field. The dimensionless form of the equations of motion for a particle in Cartesian coordinates proposed by Langmuir and Blodgett<sup>5</sup> is given as

$$\frac{dv_x}{d\tau} = \frac{C_D Re}{24} \frac{1}{K} (u_x - v_x) \quad (1)$$

$$\frac{dv_y}{d\tau} = \frac{C_D Re}{24} \frac{1}{K} (u_y - v_y) \quad (2)$$

<sup>1</sup> Stuempfle, A. K. LATR 4705. Impaction Efficiency of Cylindrical Collectors in Laminar and Turbulent Fluid Flow. Part I. Inertial Impaction Theory (U). March 1973. UNCLASSIFIED Report.

<sup>2</sup> Ranz, W. L., and Wong, J. B. Impaction of Dust and Smoke Particles on Surface and Body Collectors. Ind. Eng. Chem. 44, 1371-1381 (1952).

<sup>3</sup> Davies, C. N., and Peetz, C. V. Impingement of Particles on a Transverse Cylinder. Proc. Roy. Soc. (London) A234, 269-295 (1956).

<sup>4</sup> Householder, M. K., and Goldschmidt, V. W. The Impaction of Spherical Particles on Cylindrical Collectors. J. Colloid Interface Sci. 31, 464-478 (1969).

<sup>5</sup> Langmuir, I., and Blodgett, K. B. Air Material Command Army Air Forces. Technical Report 5418. A Mathematical Investigation of Water Droplet Trajectories. Contract W-33-038-ac-9151. General Electric Company. February 19, 1946. UNCLASSIFIED Report.

where

$v_x, v_y$  = particle velocity components normalized by the free stream velocity.

$u_x, u_y$  = airstream velocity components normalized by the free stream velocity.

$\bar{U}$  = free stream velocity at an infinite distance from the cylinder surface.

$C_D$  = drag coefficient for spherical particles in fluid.

$Re = \frac{\rho_a d_p \bar{U}}{\mu}$  = particle Reynolds number with respect to local relative velocity.

$\rho_a$  = fluid density

$\mu$  = fluid viscosity

$d_p$  = particle diameter

$$K = \frac{\rho d_p^2 \bar{U}}{18\mu R} = \text{inertial parameter of particle} \quad (3)$$

$\rho$  = particle density

$R$  = cylinder radius

$$\tau = \frac{\bar{U}}{R} t = \text{time scale}$$

The inertial parameter, K, is a measure of the inertia of the particle and relates to the magnitude of the external force required to cause a change in its direction of motion. The second important parameter used to characterize the impaction efficiency is related to the Reynolds number of the cylindrical collector and is a velocity field scaling parameter defined as

$$\phi = \frac{18 \rho_a^2 \bar{U} R}{\mu \rho} = \frac{9 \rho_a}{\rho} (Re_c) \quad (4)$$

where

$Re_c$  = free stream Reynolds number of the cylindrical collector

Representative parameter values for stylized man-sized cylindrical elements are listed in table I for unit density particles at an ambient temperature of 20°C.

The flow field around the cylindrical collector depends in part on the Reynolds number of the cylinder for steady stream conditions. When the value of the collector Reynolds number is less than one ( $\phi \approx 0.01$  in air), a closed form solution for the fluid velocity resolutes can be used to characterize the viscous flow regime.<sup>4</sup>

For intermediate collector Reynolds number ( $Re_c < 1000$ ), a transitional region between the viscous pattern and ideal flow occurs for which an analytical description of the velocity field is not available.<sup>3</sup> When the Reynolds number of the collector is one thousand or greater ( $\phi \geq 10$  in air), the flow is considered ideal in the absence of turbulence and the flow field is adequately described by potential theory. This is the flow region applicable to chemical operations (table I). For potential flow, the airstream velocity resolutes can be written in dimensionless terms as simple functions of the reduced position coordinates<sup>1</sup>; namely,

$$u_x = 1 + \frac{(y^2 - x^2)}{(x^2 + y^2)^2} \quad (5)$$

$$u_y = \mp \frac{2xy}{(x^2 + y^2)^2} \quad (6)$$

where the Cartesian coordinates have been normalized with respect to the cylinder radius.

Table I. Inertial Parameter Values, K (20°C)

Cylinder diameter cm	Windspeed mph	K			$\phi$ Parameter value	
		Particle diameter				
		20 $\mu\text{m}$	50 $\mu\text{m}$	100 $\mu\text{m}$		
35 (Body)	3	0.009	0.059	0.235	339	
	6	0.019	0.118	0.470	677	
	10	0.031	0.196	0.784	1129	
20 (Legs)	3	0.016	0.103	0.412	194	
	6	0.033	0.206	0.823	387	
	10	0.055	0.343	1.37	645	
16 (Head)	3	0.021	0.129	0.514	155	
	6	0.041	0.257	1.03	310	
	10	0.068	0.428	1.72	516	
8 (Arms)	3	0.041	0.257	1.03	77	
	6	0.082	0.514	2.05	155	
	10	0.137	0.856	3.42	258	
2 (Fingers)	3	0.164	1.03	4.11	19	
	6	0.329	2.06	8.22	39	
	10	0.548	3.43	13.70	65	

The stream function associated with the flow field described by equations 5 and 6 can be used to obtain an estimate of the impaction efficiency due to interception. Direct interception takes place when the impinging particle intersects the cylinder at a distance of one particle radius from its surface.

For a particle that has very large inertia, the inertial parameter value ( $K \rightarrow \infty$ ) can be considered so large that its straight line motion is undeviated by the flow lines (neglecting gravitational effects). The efficiency of impaction approaches the value of  $(1 + P)$  where  $P$  is the ratio of particle diameter to cylinder diameter. For a massless particle of finite size in ideal flow ( $K = 0$ ), the particle center follows the fluid streamlines. Neglecting electrostatic and other external forces, the efficiency of impaction determined by the streamlines that pass within a distance of  $1 + P$  of the collector at  $X = 0$  is found to be<sup>2,6</sup>

$$E_I = (1 + P) - \frac{1}{(1 + P)} \approx 2P \quad (7)$$

Therefore, in the limit, the theoretical incremental increase in efficiency ranges between  $P$  and  $2P$  which can amount to an infinitely large percentage change in impaction efficiency for those cases where inertial impaction theory predicts zero deposition.

It has been pointed out previously<sup>1</sup> that the impaction efficiency of point mass particles is a function of the inertial parameter,  $K$ , and the velocity field scaling parameter,  $\phi$ . Some authors have attempted to account for a finite particle to collector diameter ratio by merely adding the  $r/R$  value to the efficiency found from the theory for point mass particles. This is an incorrect procedure because each particle radius and cylinder radius corresponds to a unique  $K$  and  $\phi$  value that is associated with a particular value of impaction efficiency. Any change in one variable in turn affects a change of the impaction conditions.

The finite particle size during impaction on cylinders in ideal flow has been taken into account by modification of the computer program developed in reference 1. The fundamental inertial impaction parameters of  $K$  and  $\phi$  uniquely define the  $r/R$  ratio in the following manner.

$$K = \frac{\rho d_p^2 \bar{U}}{18\mu R} \quad (3)$$

$$\phi = \frac{18\rho_a^2 \bar{U} R}{\mu \rho} \quad (4)$$

After manipulation of terms

$$r/R = \frac{9\rho_a}{\rho} \sqrt{K/\phi} \quad (8)$$

where  $r$  = particle radius

Note that the case where  $\phi = 0$  is not allowed when considering the interception phenomenon. This condition is an artifact used in the previous study<sup>1</sup> and applies to particles that obey Stokes' drag law throughout their trajectories (i.e., by definition  $C_D Re/24 = 1$ ). For potential flow conditions to prevail,  $\phi$  should be  $\geq 10$  in air, assuming the requirement for the Reynolds number of the collector to exceed one thousand is valid. It is clearly seen from equation 8 that, to generate a theoretical impaction efficiency curve for a constant  $r/R$  ratio, the corresponding variations in  $K$  and  $\phi$  parameters must be considered.

<sup>6</sup> Luchs, N. A. The Mechanics of Aerosols. p 164. Pergamon Press Book. The Macmillan Company, New York, New York. 1964.

The digital computer program formulated in reference 1 accounted for the finite size of the particle only in calculating the drag force on the particle as its trajectory was developed. Trajectory paths were computed and continuously updated until a limiting impacting trajectory for the point mass particle was found to be within the range  $0.999999 \leq R \leq 1.000001$  of the normalized cylinder radius. Impaction efficiency was therefore determined by the initial starting  $y_0$  coordinate that produced the limiting tangent trajectory.

Modification of the trajectory path routine to include the finite particle size is readily accomplished by calculating the appropriate  $r/R$  ratio from input  $K$  and  $\phi$  parameter data (equation 8) and developing particle trajectory paths for the particle center of mass. Interception takes place when the trajectory is within one particle radius of the cylinder collector surface. The  $y_0$  coordinate and consequently the impaction efficiency is found for the limiting tangent trajectory that lies in the range  $0.999999 + r/R$  and  $1.000001 + r/R$  of the normalized collector radius.

In developing the particle path routine, the steady state value of the drag coefficient for spherical particles has been assumed to apply for each calculated point in the particle trajectory path. The computations applicable to all inertial parameter and velocity scaling parameter values of interest to chemical operations have shown that the Stokes' law region of particle drag can be exceeded at some point in the trajectory for the particle that barely escapes capture by the collector.

It has been further assumed that the ideal flow pattern around the cylindrical collector is unaffected by the presence of the particle. The maximum  $r/R$  ratio considered in developing impaction efficiency data is approximately 0.08, whereas practical ratios for chemical operations are less than 0.005 (table I).

The theory does not include the influence of a boundary layer on the cylindrical collectors and assumes that electrostatic, gravitational, and other external forces are negligible. The inertial impaction theory with interception considerations has assumed that the particle is captured upon intersection with the cylinder surface which may or may not occur in practice due to particle bounceoff, substrate properties, boundary layer shielding effects, and even particle reintrainment. Consequently, awareness and caution must be exercised when equating theoretical impaction efficiencies with actual collection efficiencies for particular collector circumstances.

### III. RESULTS AND DISCUSSION.

Computations have been performed for a wide range of  $K$  and  $\phi$  parameter input values that include and extend the range of interest for chemical operations. Inertial impaction efficiencies for particles of finite size impinging on cylindrical collectors in ideal fluid flow are graphically summarized in figure 1 for  $K \leq 0.50$ . The appendix contains a detailed listing of the calculated efficiency data with interception considerations ( $r/R > 0$ ) in addition to the efficiency data excluding interception ( $r/R = 0$ ) for the identical series of  $K$  and  $\phi$  values. Ambient conditions of  $20^\circ\text{C}$ ,  $\rho_a = 1.205 \times 10^{-3}$  gm/cu cm, and unit density spherical particles have been assumed.

Figure 2 summarizes the impaction efficiency data for  $K \leq 0.50$  when interception effects are neglected. Comparison of figures 1 and 2 reveals that interception effects are most pronounced for small values of the inertial parameter and the  $\phi$  parameter.

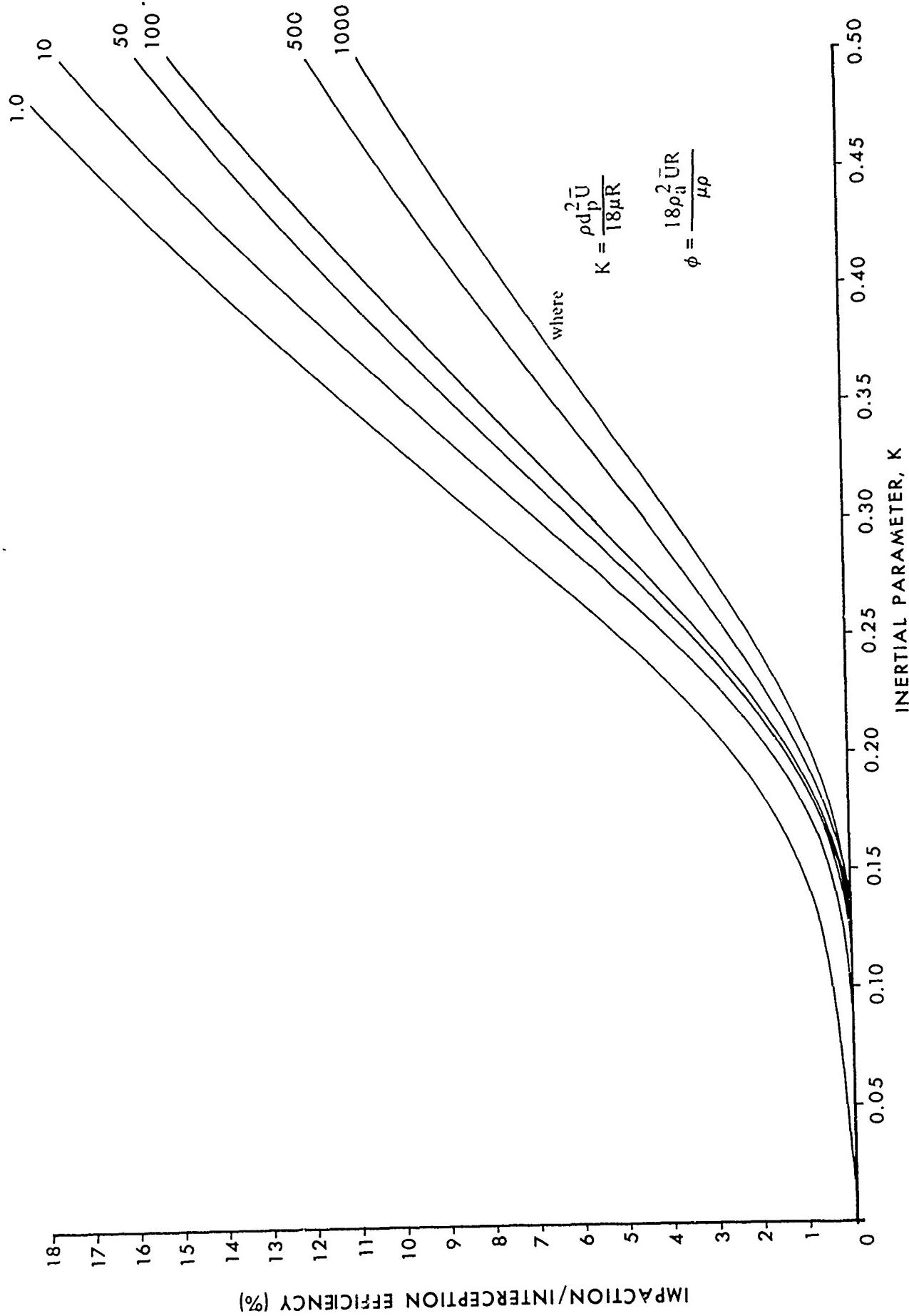


Figure 1 Impaction Efficiency With Interception for Cylinders in an Ideal Flow Field

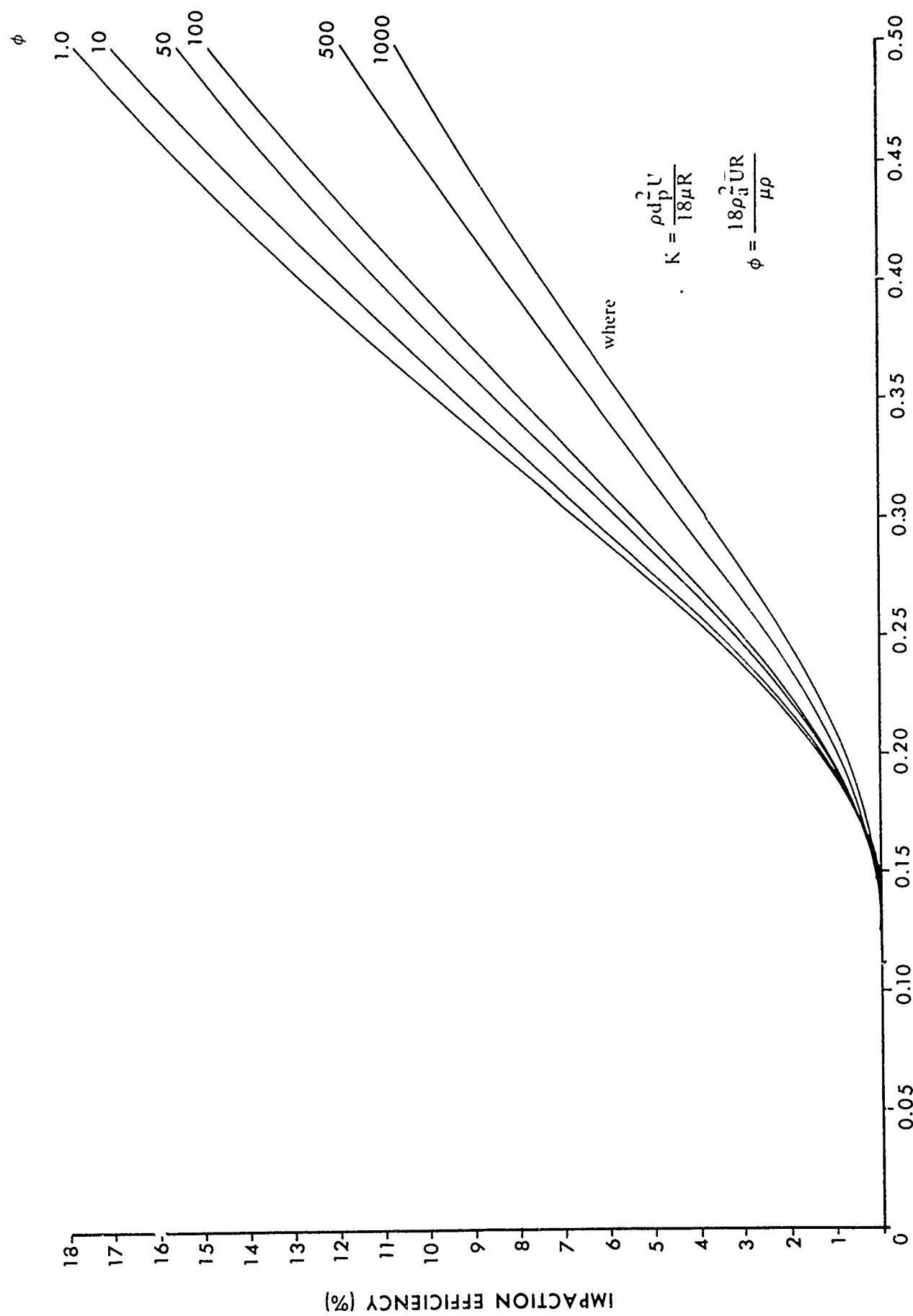


Figure 2 Impaction Efficiency Without Interception for Cylinders  
in an Ideal Flow Field

The calculated efficiencies listed in the appendix show that the percent change in impaction efficiency due to interception is insignificant for particles that possess large inertia; i.e., high values of the inertial parameter. Arbitrarily, if a 10% increase in efficiency is important, then interception effects are negligible when the inertial parameter value exceeds approximately 0.40, regardless of the particular  $\phi$  parameter value. The interception calculations predict that for high inertial parameter values ( $K \gg 64$ ) the theoretical increase in impaction efficiency approaches the theoretical limit for particles of very large inertia; namely, the efficiency approaches a value of  $1 + P$ .

On the other hand, interception can be extremely important for low values of the inertial parameter, particularly when associated with small diameter collectors. The percent change in impaction efficiency due to interception ( $\Delta E/E_0 \times 100$ ) becomes infinite for the circumstances where inertial impaction theory ( $E_0$ ) predicts zero deposition; i.e., for  $K \leq 0.125$ . Realistically, however, the change in impaction efficiency relates to the particular  $r/R$  ratio in question. The incremental increase in efficiency ( $\Delta E$ ) reaches a maximum value of approximately  $3 r/R$  when the inertial parameter value is in the region of 0.17 for essentially all values of the  $\phi$  parameter. Interestingly the computations show that, as the inertial parameter value becomes smaller and smaller, the incremental change in efficiency approaches a zero value rather than  $2P$  as predicted for the massless particle in ideal flow. This is due, of course, to the theoretical assumptions made regarding the location of the potential flow streamlines when interception takes place.

Impaction calculations have been made for  $\phi = 1.0$  which is closely associated with a collector Reynolds number in air of 100. Although this region is in the transitional flow regime mentioned earlier, the efficiencies with and without interception considerations appear reasonable in view of experimental results. Excessively high values of impaction efficiency are obtained for the interception effect when  $\phi$  is less than 1.0, implying that potential flow theory inadequately describes the fluid flow field.

Figure 3 summarizes the range of impaction efficiencies for a wide variation of  $K$  and  $\phi$  parameter values.

The Householder and Goldschmidt study<sup>4</sup> of the impaction of spherical particles on cylindrical collectors attempts to predict impaction efficiencies for all ratios of particle to collector sizes and to bridge the transitional flow region of collector Reynolds number. The authors provide several graphs of collection coefficients as determined by various experimental and theoretical studies for particular small particle to collector diameter ratios. A mathematical model is proposed that generally yields an acceptable fit to the rather limited data. The independent variable is given as a function of the collector Reynolds number rather than the inertial parameter,  $K$ . However, because the  $K$  and  $\phi$  parameters uniquely define the  $P$  ratio, as discussed earlier, and since  $\phi$  is directly proportional to the collector Reynolds number, the data generated herein can be easily compared with their results and excellent agreement is achieved with those reported experimental studies conducted under potential flow circumstances (including  $\phi = 1.0$ ). Notably lacking in the reported studies are collection efficiency data for low inertial parameter values and large  $\phi$  parameters. This gap is currently being satisfied by experimental studies which are being conducted in-house and which will be reported in part III of this series.

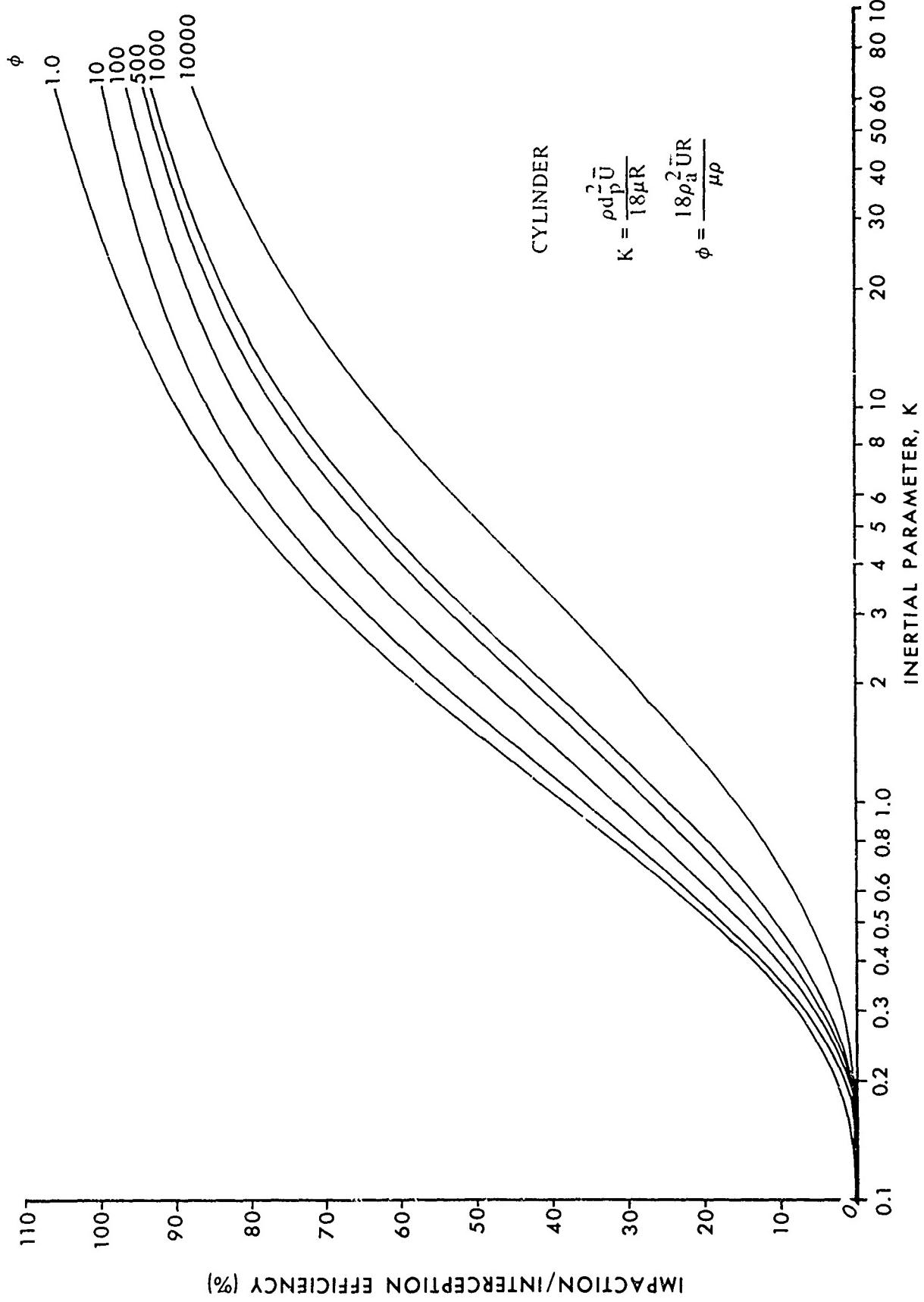


Figure 3 Impaction Efficiency With Interception Effect

The interception effect becomes increasingly important as the theoretical cutoff value of the inertial impaction theory is approached, assuming that the boundary layer developed at the collector surface can be ignored. The critical K value of 0.125 for point mass particles below which impingement on the cylinder surface is precluded is no longer a valid condition when the particles possess a finite size. Analysis of the particle trajectories shows that a critical K value still exists for interception considerations but its value is substantially reduced depending on the  $\phi$  parameter of interest. With unit density particles in air, an inertial parameter value that is less than 0.05 for all values of the  $\phi$  parameter greater than 500 yields a computer generated impaction efficiency less than  $10^{-5}$ , which is considered to be zero for all practical circumstances. In the absence of turbulence, electrostatic effects, and other external forces acting on the particle, theoretical values of impaction efficiency can be obtained for all cases of interest to chemical operations. The calculated efficiencies after accounting for the interception effect are listed in table II and correspond to the conditions given in table I.

Table II. Impaction Efficiency With Interception Effect

Cylinder diameter cm	Windspeed mph	Impaction efficiency		
		Particle diameter		
		20 $\mu\text{m}$	50 $\mu\text{m}$	100 $\mu\text{m}$
35 (Body)	3	0	0.004	2.1
	6	0	0.018	10.4
	10	0	0.68	18.8
20 (Legs)	3	0	0.022	10.2
	6	0	1.2	23.2
	10	0.002	5.8	33.5
16 (Head)	3	0	0.059	14.8
	6	0.002	3.0	29.1
	10	0.004	9.4	39.9
8 (Arms)	3	0.006	3.7	32.9
	6	0.013	14.8	48.5
	10	0.064	25.3	58.7
2 (Fingers)	3	0.52	35.7	69.9
	6	7.6	52.6	80.3
	10	17.7	63.1	85.8

It must be emphasized again that the calculated impaction efficiencies may not equal the collection efficiencies experienced in practice. This is particularly true under field conditions where the flow field is normally turbulent in nature. Experimental studies under controlled turbulent conditions to be included in part III of this series have shown that the collection efficiency of cylinders is a function of the turbulence intensity and Eulerian macroscale of the turbulence field. Under some turbulence conditions, measured collection efficiencies for small K parameter values have exceeded efficiencies predicted by the inertial impaction theory by a

factor of ten. However, under laminar flow with all other experimental conditions being equal, the same inertial impaction theory given herein accurately predicts the measured collection efficiency. As a result, the interception effect when incorporated in and coupled with the inertial impaction theory developed in reference 1 provides a reasonable estimate of the impaction efficiencies to be expected for cylindrical collectors in a laminar flow field.

#### IV. CONCLUSIONS.

1. The finite size of spherical particles has been incorporated in the inertial impaction theory in order to calculate the impaction efficiencies of cylindrical collectors in potential fluid flow.
2. Impaction efficiencies with interception effects have been obtained by use of digital computer techniques for practical circumstances of interest to chemical operations.
3. The theoretical results have been reduced to graphic form of impaction efficiency as a function of the inertial parameter and velocity scaling parameter.
4. The critical inertial parameter value for zero deposition has been calculated for interception considerations and is substantially less than the cutoff value predicted by standard impaction theory.
5. All calculated impaction efficiencies resulting from interception considerations are greater than the corresponding efficiencies without interception.

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APPENDIX  
IMPACTION EFFICIENCIES WITH AND WITHOUT INTERCEPTION CONSIDERATIONS

Velocity scaling parameter $\phi$	Inertial parameter K	r/R	Efficiency with interception $E_I$	Inertial impaction efficiency $E_O$	$\Delta E$ ( $E_I - E_O$ )	$\frac{\Delta E}{r/R}$	$\frac{\Delta E}{E_O} \times 100$
1.0*	0.04	0.002168	0.00109	0	0.00109	0.50	-
	0.05	0.002424	0.00140	0	0.00140	0.58	-
	0.10	0.003429	0.00388	0	0.00388	1.13	-
	0.125	0.003833	0.00627	0	0.00627	1.64	-
	0.13	0.003909	0.00687	0	0.00687	1.76	-
	0.14	0.004057	0.00838	0.00008	0.00830	2.05	10375
	0.15	0.004199	0.01025	0.00056	0.00969	2.31	1730
	0.16	0.004337	0.01250	0.00173	0.01077	2.48	623
	0.17	0.004470	0.01513	0.00365	0.01148	2.57	315
	0.175	0.004536	0.01671	0.00481	0.01190	2.62	247
	0.20	0.004849	0.02587	0.01325	0.01262	2.60	95
	0.25	0.005421	0.05093	0.03769	0.01324	2.44	35
	0.30	0.005939	0.07958	0.06698	0.01260	2.12	19
	0.35	0.006414	0.10953	0.09685	0.01268	1.98	13
	0.45	0.007273	0.16585	0.15337	0.01248	1.72	8.1
	0.50	0.007667	0.19361	0.17976	0.01385	1.81	7.7
	0.60	0.008398	0.24100	0.22794	0.01306	1.56	5.7
	0.70	0.009071	0.28510	0.27070	0.01440	1.59	5.3
	0.80	0.009698	0.32332	0.30903	0.01429	1.47	4.6
	0.90	0.010286	0.35678	0.34239	0.01439	1.40	4.2
	1.0	0.010842	0.38658	0.37197	0.01461	1.35	3.9
	2.0	0.015333	0.58200	0.56356	0.01844	1.20	3.3
	4.0	0.021685	0.74481	0.72096	0.02385	1.10	3.3
	8.0	0.030667	0.86574	0.83353	0.03221	1.05	3.9
	16.0	0.043369	0.95002	0.90550	0.04452	1.03	4.9
	32.0	0.061333	1.01024	0.94802	0.06222	1.01	6.6
	40.0	0.068573	1.02670	0.95729	0.06941	1.01	7.2
	64.0	0.086738	1.05927	0.97188	0.08739	1.01	9.0
10	0.04	0.000686	0.00023	0	0.00023	0.34	-
	0.05	0.000767	0.00031	0	0.00031	0.40	-
	0.10	0.001084	0.00106	0	0.00106	0.98	-
	0.125	0.001212	0.00198	0	0.00198	1.63	-
	0.13	0.001236	0.00228	0	0.00228	1.84	-
	0.14	0.001283	0.00301	0.00007	0.00294	2.29	4200
	0.15	0.001328	0.00406	0.00952	0.00354	2.67	681
	0.16	0.001371	0.00559	0.00159	0.00400	2.92	252
	0.17	0.001414	0.00760	0.00335	0.00425	3.01	127
	0.175	0.001434	0.00870	0.00453	0.00417	2.91	92
	0.20	0.001533	0.01682	0.01253	0.00429	2.80	34
	0.25	0.001714	0.03965	0.03566	0.00399	2.33	11
	0.30	0.001878	0.06768	0.06332	0.00436	2.32	6.9
	0.35	0.002028	0.09616	0.09186	0.00430	2.12	4.7
	0.45	0.002300	0.15017	0.14603	0.00414	1.80	2.8
	0.50	0.002424	0.17522	0.17060	0.00462	1.91	2.7
	0.60	0.002656	0.22117	0.21685	0.00432	1.63	2.0
	0.70	0.002869	0.26217	0.25740	0.00477	1.66	1.9
	0.80	0.003067	0.29887	0.29414	0.00473	1.54	1.6
	0.90	0.003253	0.33077	0.32601	0.00476	1.46	1.5
	1.0	0.003429	0.35908	0.35425	0.00483	1.41	1.4
	2.0	0.004849	0.54725	0.54115	0.00610	1.26	1.1
	4.0	0.006857	0.70592	0.69805	0.00787	1.15	1.1
	8.0	0.009698	0.82464	0.81412	0.01052	1.08	1.3
	16.0	0.013715	0.90540	0.89100	0.01440	1.05	1.6
	32.0	0.019395	0.95795	0.93798	0.0197	1.03	2.1
	40.0	0.021685	0.97070	0.94847	0.02223	1.03	2.3
	64.0	0.027429	0.99317	0.96525	0.02792	1.02	2.9

\* Potential fluid flow may not apply when  $\phi = 1.0$

Velocity scaling parameter $\phi$	Inertial parameter K	r/R	Efficiency with interception $E_I$	Inertial impactation efficiency $E_O$	$\Delta E (E_I - E_O)$	$\frac{\Delta I}{r/R}$	$\frac{\Delta I}{E_O} \times 100$
50	0.04	0.000307	0.00008	0	0.00008	0.26	-
	0.05	0.000343	0.00011	0	0.00011	0.32	-
	0.10	0.000485	0.00043	0	0.00043	0.89	-
	0.125	0.000542	0.00089	0	0.00089	1.64	-
	0.13	0.000553	0.00105	0	0.00105	1.90	-
	0.14	0.000574	0.00149	0.00006	0.00143	2.49	2383
	0.15	0.000594	0.00224	0.00048	0.00176	2.96	367
	0.16	0.000613	0.00339	0.00147	0.00192	3.13	131
	0.17	0.000632	0.00510	0.00309	0.00201	3.18	65
	0.175	0.000641	0.00615	0.00416	0.00199	3.10	48
	0.20	0.000686	0.01342	0.01147	0.00195	2.84	17
	0.25	0.000767	0.03492	0.03299	0.00193	2.52	5.9
	0.30	0.000840	0.05978	0.05767	0.00211	2.51	3.6
	0.35	0.000907	0.08583	0.08376	0.00207	2.28	2.5
	0.45	0.001029	0.13600	0.13403	0.00197	1.91	1.5
	0.50	0.001084	0.15785	0.15579	0.00206	1.90	1.3
	0.60	0.001188	0.20176	0.19971	0.00205	1.73	1.0
	0.70	0.001283	0.23929	0.23702	0.00227	1.77	0.96
	0.80	0.001371	0.27421	0.27196	0.00225	1.64	0.83
	0.90	0.001455	0.30436	0.30211	0.00225	1.55	0.74
	1.0	0.001533	0.33102	0.32874	0.00228	1.49	0.69
	2.0	0.002168	0.51257	0.50969	0.00288	1.33	0.57
	4.0	0.003067	0.67069	0.66701	0.00368	1.20	0.55
	8.0	0.004337	0.79335	0.78846	0.00489	1.13	0.62
	16.0	0.006133	0.87873	0.87213	0.00660	1.08	0.76
	32.0	0.008674	0.93426	0.92518	0.00908	1.05	0.98
	40.0	0.009698	0.94740	0.93731	0.01009	1.04	1.1
	64.0	0.012267	0.96959	0.95698	0.01261	1.03	1.3
100	0.04	0.000217	0.00005	0	0.00005	0.23	-
	0.05	0.000242	0.00007	0	0.00007	0.29	-
	0.10	0.000343	0.00029	0	0.00029	0.85	-
	0.125	0.000383	0.00063	0	0.00063	1.64	-
	0.13	0.000391	0.00075	0	0.00075	1.92	-
	0.14	0.000406	0.00111	0.00006	0.00105	2.59	1750
	0.15	0.000420	0.00172	0.00045	0.00127	3.02	282
	0.16	0.000434	0.00278	0.00139	0.00139	3.20	100
	0.17	0.000447	0.00435	0.00293	0.00142	3.18	48
	0.175	0.000454	0.00528	0.00393	0.00135	2.97	34
	0.20	0.000485	0.01230	0.01083	0.00147	3.03	14
	0.25	0.000542	0.03237	0.03094	0.00143	2.64	4.6
	0.30	0.000594	0.05532	0.05408	0.00124	2.09	2.3
	0.35	0.000641	0.07972	0.07818	0.00154	2.40	2.0
	0.45	0.000727	0.12771	0.12625	0.00146	2.01	1.2
	0.50	0.000767	0.14890	0.14752	0.00138	1.80	0.94
	0.60	0.000840	0.19060	0.18910	0.00150	1.79	0.79
	0.70	0.000907	0.22597	0.22429	0.00168	1.85	0.75
	0.80	0.000970	0.25996	0.25832	0.00164	1.69	0.63
	0.90	0.001029	0.28923	0.28759	0.00164	1.59	0.57
	1.0	0.001084	0.31510	0.31343	0.00167	1.54	0.53
	2.0	0.001533	0.49319	0.49110	0.00209	1.36	0.43
	4.0	0.002168	0.65128	0.64861	0.00267	1.23	0.41
	8.0	0.003067	0.77662	0.77310	0.00352	1.15	0.46
	16.0	0.004337	0.86570	0.86096	0.00474	1.09	0.55
	32.0	0.006133	0.92407	0.91758	0.00649	1.06	0.71
	40.0	0.006857	0.93786	0.93068	0.00718	1.05	0.77
	64.0	0.008674	0.96103	0.95205	0.00898	1.04	0.94

Velocity scaling parameter $\phi$	Inertial parameter K	$r/R$	Efficiency with interception $E_I$	Inertial impact ion efficiency $E_O$	$\Delta E (E_I - E_O)$	$\frac{\Delta E}{r/R}$	$\frac{\Delta E}{E_O} \times 100$
500	0.05	0.000108	0.00002	0	0.00002	0.19	-
	0.10	0.000153	0.00012	0	0.00012	0.78	-
	0.125	0.000171	0.00028	0	0.00028	1.64	-
	0.13	0.000175	0.00034	0	0.00034	1.94	-
	0.14	0.000181	0.00055	0.00005	0.00050	2.76	1000
	0.15	0.000188	0.00098	0.00036	0.00092	3.30	172
	0.16	0.000194	0.00176	0.00111	0.00065	3.35	59
	0.17	0.000200	0.00302	0.00233	0.00069	3.45	30
	0.175	0.000203	0.00377	0.00316	0.00061	3.00	19
	0.20	0.000217	0.00931	0.00872	0.00059	2.72	6.8
	0.25	0.000242	0.02516	0.02457	0.00059	2.44	2.4
	0.30	0.000266	0.04401	0.04335	0.00066	2.48	1.5
	0.35	0.000287	0.06405	0.06341	0.00064	2.23	1.0
	0.45	0.000325	0.10227	0.10165	0.00062	1.91	0.61
	0.50	0.000343	0.12185	0.12114	0.00071	2.07	0.59
	0.60	0.000376	0.15645	0.15568	0.00077	2.05	0.49
	0.70	0.000406	0.18847	0.18774	0.00073	1.80	0.39
	0.80	0.000434	0.21742	0.21659	0.00083	1.91	0.38
	0.90	0.000460	0.24492	0.24410	0.00082	1.78	0.34
	1.0	0.000485	0.26903	0.26821	0.00082	1.69	0.31
	2.0	0.000686	0.43653	0.43552	0.00101	1.47	0.23
	4.0	0.000970	0.59699	0.59569	0.00130	1.34	0.22
	8.0	0.001371	0.73032	0.72864	0.00168	1.23	0.23
	16.0	0.001940	0.82874	0.82653	0.00221	1.14	0.27
	32.0	0.002743	0.89603	0.89304	0.00299	1.09	0.33
	40.0	0.003067	0.91240	0.90908	0.00332	1.08	0.37
	64.0	0.003879	0.93984	0.93574	0.00410	1.06	0.44
1000	0.05	0.000077	0.00002	0	0.00002	0.26	-
	0.10	0.000108	0.00008	0	0.00008	0.74	-
	0.125	0.000121	0.00019	0	0.00019	1.60	-
	0.13	0.000124	0.00024	0	0.00024	1.94	-
	0.14	0.000128	0.00041	0.00004	0.00037	2.89	925
	0.15	0.000133	0.00075	0.00032	0.00043	3.22	134
	0.16	0.000137	0.00140	0.00097	0.00043	3.14	44
	0.17	0.000141	0.00250	0.00207	0.00043	3.05	21
	0.175	0.000143	0.00322	0.00277	0.00045	3.15	16
	0.20	0.000153	0.00793	0.00746	0.00047	3.07	6.3
	0.25	0.000171	0.02151	0.02105	0.00046	2.69	2.2
	0.30	0.000188	0.03775	0.03735	0.00040	2.13	1.1
	0.35	0.000203	0.05525	0.05475	0.00050	2.46	0.91
	0.45	0.000230	0.09067	0.09019	0.00048	2.09	0.53
	0.50	0.000242	0.10714	0.10660	0.00054	2.23	0.51
	0.60	0.000266	0.13877	0.13828	0.00049	1.84	0.35
	0.70	0.000287	0.16965	0.16909	0.00056	1.95	0.33
	0.80	0.000307	0.19565	0.19511	0.00054	1.76	0.28
	0.90	0.000325	0.22225	0.22163	0.00062	1.91	0.28
	1.0	0.000343	0.24572	0.24511	0.00061	1.78	0.25
	2.0	0.000485	0.40719	0.40644	0.00075	1.55	0.18
	4.0	0.000686	0.56797	0.56701	0.00096	1.40	0.17
	8.0	0.000970	0.70526	0.70404	0.00122	1.26	0.17
	16.0	0.001371	0.80926	0.80766	0.00160	1.17	0.20
	32.0	0.001940	0.88097	0.87881	0.00216	1.11	0.25
	40.0	0.002168	0.89842	0.89604	0.00238	1.10	0.27
	64.0	0.002743	0.92865	0.92570	0.00295	1.08	0.32

Velocity scaling parameter $\phi$	Inertial parameter K	$r/R$	Efficiency with interception $F_1$	Inertial impact efficiency $F_0$	$\Delta F$ ( $F_1 - F_0$ )	$\frac{\Delta F}{r/R}$	$\frac{\Delta F}{F_0} \times 100$ %
10,000	0.10	0.000034	0.00002	0	0.00002	0.59	-
	0.125	0.000038	0.00006	0	0.00006	1.58	-
	0.13	0.000039	0.00007	0	0.00007	1.79	-
	0.14	0.000041	0.00013	0.00002	0.00011	2.68	550
	0.15	0.000042	0.00028	0.00015	0.00013	3.10	87
	0.16	0.000043	0.00061	0.00047	0.00014	3.26	30
	0.17	0.000045	0.00111	0.00098	0.00013	2.89	13
	0.175	0.000045	0.00141	0.00128	0.00013	2.89	10
	0.20	0.000048	0.00358	0.00346	0.00012	2.50	3.5
	0.25	0.000054	0.01006	0.00995	0.00011	2.04	1.1
	0.30	0.000059	0.01854	0.01842	0.00012	2.03	0.65
	0.35	0.000064	0.02811	0.02794	0.00017	2.66	0.61
	0.45	0.000073	0.04899	0.04884	0.00015	2.05	0.31
	0.50	0.000077	0.06008	0.05991	0.00017	2.21	0.28
	0.60	0.000084	0.08124	0.08105	0.00019	2.26	0.23
	0.70	0.000091	0.10126	0.10106	0.00020	2.20	0.20
	0.80	0.000097	0.12079	0.12059	0.00020	2.06	0.17
	0.90	0.000103	0.13950	0.13928	0.00022	2.14	0.16
	1.0	0.000108	0.15799	0.15777	0.00022	2.04	0.14
	2.0	0.000153	0.29431	0.29402	0.00029	1.89	0.10
	4.0	0.000217	0.44627	0.44591	0.00036	1.66	0.08
	8.0	0.000307	0.59129	0.59085	0.00044	1.43	0.07
	16.0	0.000434	0.71392	0.71334	0.00058	1.34	0.08
	32.0	0.000613	0.80802	0.80726	0.00076	1.24	0.09
	40.0	0.000686	0.83217	0.83134	0.00083	1.21	0.10
	64.0	0.000867	0.87427	0.87327	0.00100	1.15	0.11

Velocity scaling parameter $\phi$	Inertial parameter K	$r/R$	Efficiency with interception $I_I$	Inertial impaction efficiency $I_o$	$\Delta I / (I_I + I_o)$	$\frac{\Delta I}{r/R}$	$\frac{\Delta I}{I_o} \times 100$
19	0.164	0.001007	0.00524	0.00217	0.00307	3.05	1.41
19	1.03	0.002524	0.35700	0.35341	0.00359	1.42	1.02
19	4.11	0.005043	0.69868	0.69281	0.00587	1.16	0.85
39	0.329	0.000996	0.07627	0.07424	0.00203	2.04	2.73
39	2.06	0.002492	0.52617	0.52291	0.00326	1.31	0.62
39	8.22	0.004978	0.80276	0.79720	0.00556	1.12	0.70
65	0.548	0.000996	0.17653	0.17465	0.00188	1.89	1.08
65	3.43	0.002491	0.63127	0.62819	0.00308	1.24	0.49
65	13.70	0.004978	0.85750	0.85207	0.00543	1.09	0.64
77	0.041	0.000250	0.00006	0	0.00006	25	"
77	0.257	0.000626	0.03654	0.03505	0.00149	2.38	4.2%
77	1.03	0.001254	0.32873	0.32680	0.00193	1.54	0.59
155	0.021	0.000126	0	0	0	0	0
155	0.082	0.000249	0.00013	0	0.00013	0.52	"
155	0.129	0.000313	0.00059	<10 <sup>-5</sup>	0.00059	1.88	"
155	0.514	0.000624	0.14779	0.14667	0.00112	1.79	0.76
155	2.05	0.001247	0.48549	0.48376	0.00173	1.39	0.36
194	0.016	0.000098	0	0	0	0	0
194	0.103	0.000250	0.00022	0	0.00022	0.88	"
194	0.412	0.000500	0.10158	0.10061	0.00097	1.94	0.96
258	0.137	0.000250	0.00064	0.00002	0.00062	2.48	31
258	0.856	0.000625	0.25276	0.25168	0.00108	1.73	0.43
258	3.42	0.001248	0.58730	0.58563	0.00167	1.34	0.28
310	0.041	0.000125	0.00002	0	0.00002	0.16	"
310	0.257	0.000313	0.03009	0.02924	0.00085	2.72	2.91
310	1.03	0.000625	0.29076	0.28975	0.00101	1.62	0.35
339	0.009	0.000056	0	0	0	0	0
339	0.059	0.000143	0.00004	0	0.00004	0.28	"
339	0.235	0.000286	0.02137	0.02055	0.00082	2.87	3.99
387	0.033	0.000100	0	0	0	0	0
387	0.206	0.000250	0.01154	0.01080	0.00074	2.96	6.85
387	0.823	0.000500	0.23182	0.23091	0.00091	1.82	0.39
516	0.068	0.000124	0.00004	0	0.00004	0.32	"
516	0.428	0.000313	0.09413	0.09349	0.00064	2.04	0.68
516	1.72	0.000625	0.39933	0.39837	0.00096	1.54	0.24
645	0.055	0.000100	0.00002	0	0.00002	0.20	"
645	0.343	0.000250	0.05811	0.05750	0.00061	2.44	1.06
645	1.37	0.000500	0.33541	0.33457	0.00084	1.68	0.25
677	0.019	0.000057	0	0	0	0	0
677	0.118	0.000143	0.00018	0	0.00018	1.26	"
677	0.470	0.000286	0.10398	0.10332	0.00066	2.31	0.64
1129	0.031	0.000057	0	0	0	0	0
1129	0.196	0.000143	0.00681	0.00642	0.00039	2.73	6.07
1129	0.784	0.000286	0.18824	0.18773	0.00051	1.78	0.27

## UNCLASSIFIED

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13. ABSTRACT The inertial impaction of finite sized particles impinging on man-sized cylindrical elements in an ideal flow field has been studied by use of digital computer techniques. The interception effect resulting from consideration of finite particle size can theoretically increase the inertial impaction efficiency by an order of magnitude for small values of the particle inertial parameter and velocity scaling parameter. The theoretical results have been reduced to graphic form of impaction efficiency versus inertial parameter for all circumstances of interest in chemical operations and have been compared with the theoretical impaction efficiency data for point mass particles. The existence of a critical inertial parameter value for zero deposition is indicated but numerically is substantially less than the classical theory value without interception considerations.		
14. KEYWORDS		
Droplet Aerosols Sampling Particles Impaction Cylinders Collectors	Deposition Efficiency Turbulence Wind tunnel Impingement Interception Particle impaction	Inertial impaction Inertial parameter Isokinetic sampling Sampling efficiency Impaction efficiency Collection efficiency Deposition efficiency